# Novel Optical Investigations of Spin Dependent Effects in Semiconductor Nanostructures

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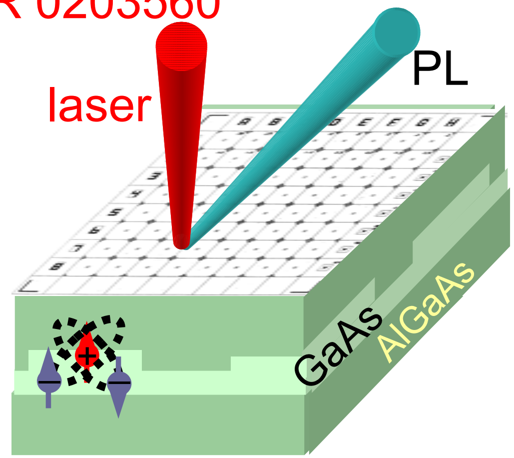
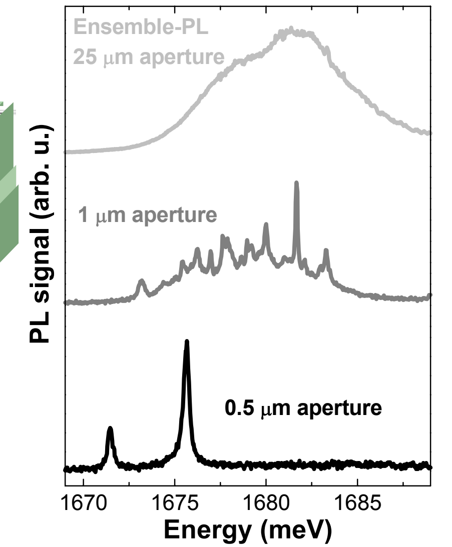
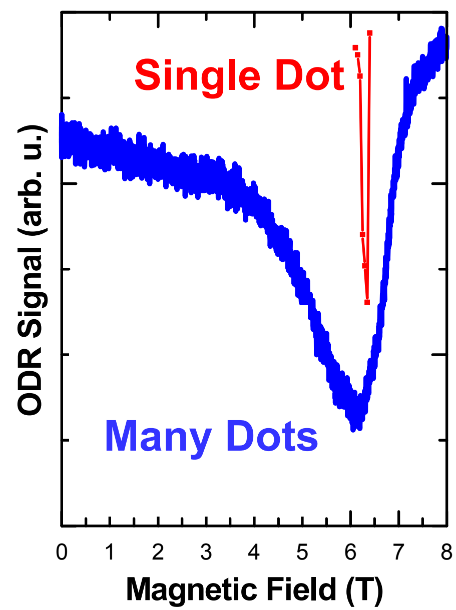
We are probing the excited states of negative trions (two electrons bound to a hole) in “natural” quantum dots formed by controlled fluctuations in thickness of a thin layer (0.28 nm) of one semiconductor sandwiched between thick layers of another. We use a sensitive optical technique - optically detected resonance (ODR) spectroscopy - for these studies. The lower figure shows the ODR spectrum - changes in strength of the emitted photoluminescence induced by resonant absorption of teraherz (THz) radiation - from a large number of dots of different lateral dimensions, and from a single dot. The maximum negative signal corresponds to promoting one of the two electrons to a higher energy state. This first observation of internal transitions of a charged complex in a <u>single dot</u> demonstrates the possibility of manipulating the state of the trion by THz radiation. Comparison with theory will permit improved understanding and help to define possible applications in quantum information technology.




Structure and indexed array of apertures in an Al mask for studying single dots. Trions are localized in the thicker areas.




Photoluminescence (PL) spectra from apertures of the indicated diameters in a GaAs layer of average thickness 2.8 nm.




Optically Detected Resonance Spectra of an ensemble of dots and a single dot in a GaAs layer of 2.8 nm average thickness

We are rapidly approaching the end of several decades of rapid increases in data processing capacity (doubling every three years) that have produced remarkable economic growth and have pervasively impacted our society. Fundamental physical limits associated with shrinking the size of digital logic circuits dictate the end of this continued growth within the next 20 years. These conventional digital computers and processing technologies, which have fueled our information economy, make use of moving the electron charge in integrated circuits to represent the “zeros” and “ones” (the computer bits) and to perform digital computation. Entirely new approaches are needed for future generations of information technology to continue the remarkable growth seen over the past several decades. Quantum Computing and Quantum Information Processing represent one such paradigm. Quantum logic uses the infinite number of combinations of states of a two-level system that are allowed by quantum mechanics as the basis of quantum bits or “qubits’; this can lead to great improvements in certain types of computing and in encryption for secure communications. The electron spin, another fundamental property of the electron, is an ideal two-level system and is thus a natural quantum bit; as such it plays a central role in many approaches to quantum computing. One of these approaches involves controlling the states of the electron spin in nanosized quantum dots by light. By shining polarized light on a quantum dot containing an electron, one can produce a bound two-electron/one hole complex called a trion, in which the electrons have known total spin, and after one of the electrons recombines with the hole the spin state of the electron remaining in the quantum dot can be “read out” by polarization of the light emitted (the luminescence). We are studying the internal structure of such trions by a very sensitive technique called optically detected resonance spectroscopy, as illustrated in the slide. We have demonstrated for the first time that it is possible to probe the internal energy and spin structure of this two-electron-one hole complex with light in the far infrared, or terahertz (THz), region of the spectrum. We believe that manipulating an optically produced trion via THz radiation is possible and may provide new ways of probing and controlling quantum information in quantum dots.

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## Education

Four graduate students and one undergraduate student have been involved in this work. One Ph.D. student will finish in the fall of 2004. He already has several groups Interested in hiring him for a post-doctoral position. The PI has given two general public educational lectures since 2002, entitled "What in the world is Spintronics", in an effort to demystify this emerging technology.

## Broader Impact

New paradigms are needed for future generations of information technology to maintain the remarkable growth that has so pervasively impacted our society. Quantum computing/information processing is one possible new paradigm, and the electron spin (rather than its charge) is receiving much attention as a natural two-level system for quantum bits, or "qubits" for quantum computation. One possibility for producing and manipulating spins in nanosized quantum dots involves the bound two-electron/one hole complex called a negative trion. Further understanding of this complex and how to manipulate it optically via THz radiation may provide new avenues for developing Quantum Information Technology.